

Plans for liquid lithium wall experiments in CDX-U

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Liquid lithium experiments in CDX-U

- ◆ Liquid metal walls and divertors have been identified as a potentially revolutionary solution to the plasma-wall interaction problem.
- ◆ In addition, a liquid metal wall in close proximity to the last closed flux surface may significantly enhance stability and performance (L. Zakharov, M. Katsenreuther).
 - Low/no recycling edge.
 - » Advantages demonstrated during the TFTR pellet, effusion oven, and DOLLOP experiments.
 - Higher allowable κ , higher β - $>20\%$ for conventional A (Zakharov).
- ◆ Liquid *lithium* offers the best synthesis of desirable properties.
 - But *no one* wants to fill a PoP or PE level device with liquid lithium!
- ◆ As a first step, the CDX-U program has now been given over *entirely* to the testing of liquid metal limiter, divertor and wall concepts.
- ◆ Part of the ALPS/APEX liquid divertor/walls initiative.

Physics and technology issues for liquid lithium

- ◆ Lithium plasma fueling and core impurity accumulation.
 - Temperature rise during plasma operation will ramp evaporation rate.
- ◆ Plasma edge with a very low recycling limiter.
- ◆ Fueling with hydrogenics.
 - CDX-U utilizes gas puffing; no core fueling at present.
- ◆ Consequences of possible surface coatings formed in situ.
 - Lithium nitride layer may form during introduction into vessel.
 - Lithium deuteride surface may form during plasma operation.
 - » LiD melts at 688°C but is highly soluble in lithium.
- ◆ Lithium handling.
 - Loading, purification, pacification.

Physics and technology issues for liquid lithium

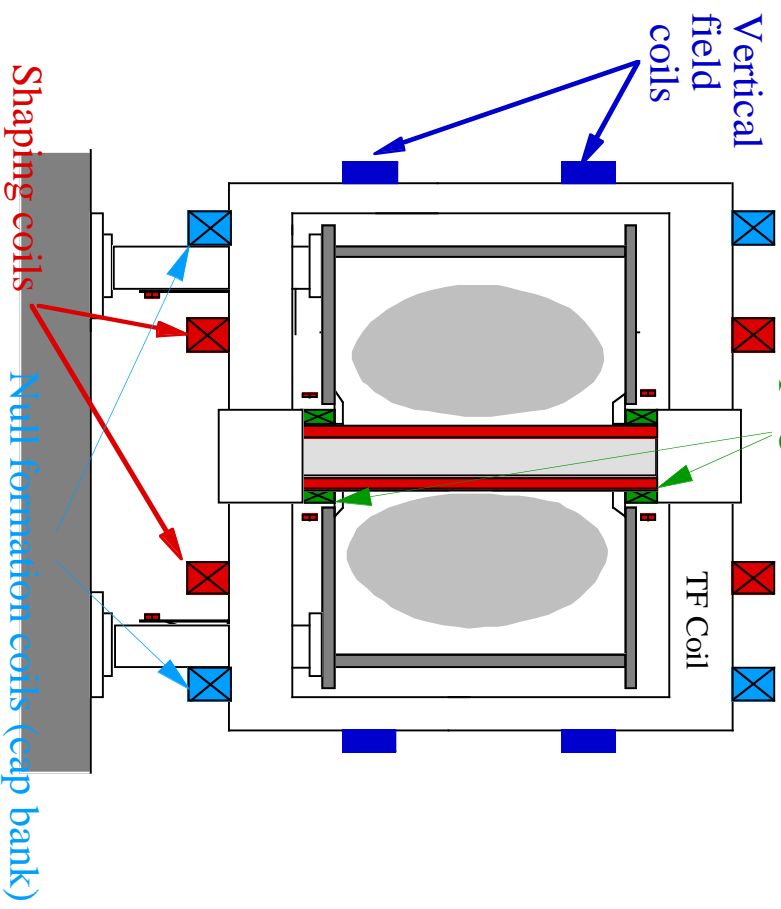
- ◆ Can lithium or any other liquid metal PFC be forced to behave during a tokamak discharge?
 - Liquid motion during PF coil ramps.
 - » Toroidal currents can flow within continuous lithium divertor target.
 - » Might affect position control or MHD stability (partial conducting shell).
 - Motion during a VDE.
 - Halo current - induced $\mathbf{j} \times \mathbf{B}$ forces.
 - » Lithium propulsion is not a research goal.
- ◆ Electromagnetic restraint may be necessary.

Liquid lithium tests in CDX-U

- ◆ Staged approach:
 - Liquid lithium rail limiter will be the first step.
 - » Designed and fabricated at UCSD.
 - » Lithium capillary (mesh) system.
- ◆ Toroidal liquid lithium belt limiter will follow.
 - PPPL/Sandia/Argonne/UCSD collaboration.
- ◆ CDX-U PF system will be augmented to allow single-null operation with strike points on the belt limiter system.
- ◆ Future tests:
 - Flowing lithium.
 - Partial wall coverage.

CDX-U

Eddy current cancellation,
shaping coils

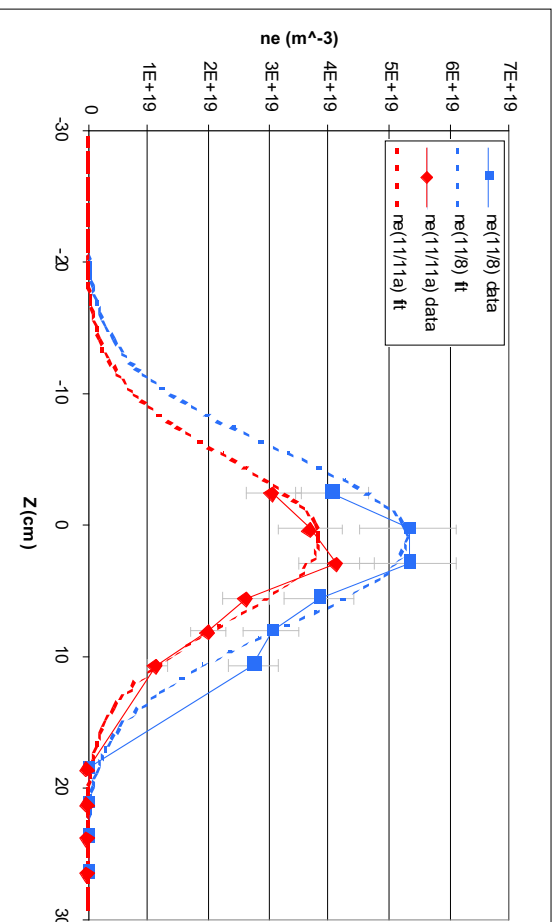


CDX-U is a START-scale
spherical torus.

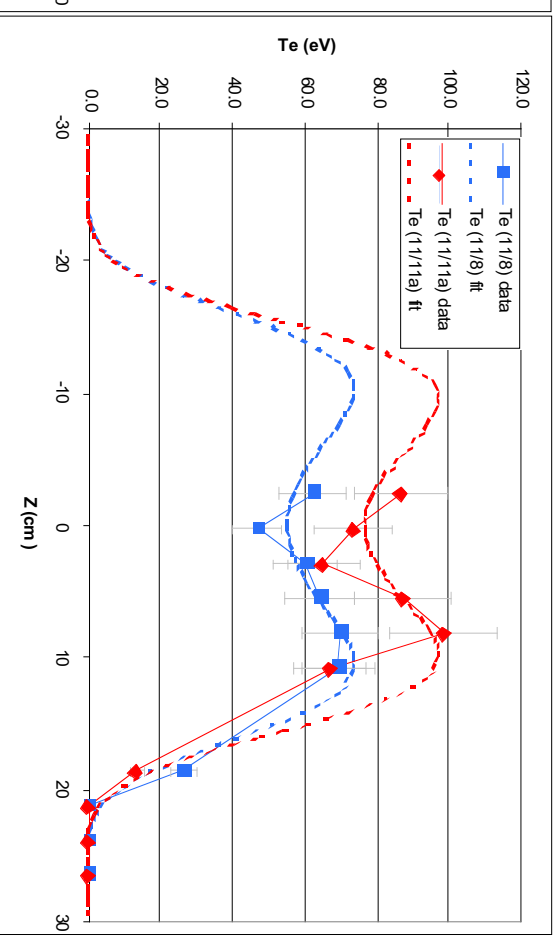
- ◆ $R_0 = 34$ cm
- ◆ $a = 22$ cm
- ◆ $A \equiv R_0/a \geq 1.5$
- ◆ $\kappa \leq 1.7$
- ◆ $\delta > 0.2$
- ◆ $B_t \leq 0.22$ Tesla
- ◆ Ohmic $I_p \leq 100$ kA
- ◆ $n_e(0) < 5 \times 10^{13} \text{ cm}^{-3}$.
- ◆ $T_e \sim 100$ eV
- ◆ $P_{\text{auxiliary}} \leq 300$ kW (rf)
- ◆ Discharge duration: 20-40 msec

Density and temperature profiles from multipoint Thomson scattering

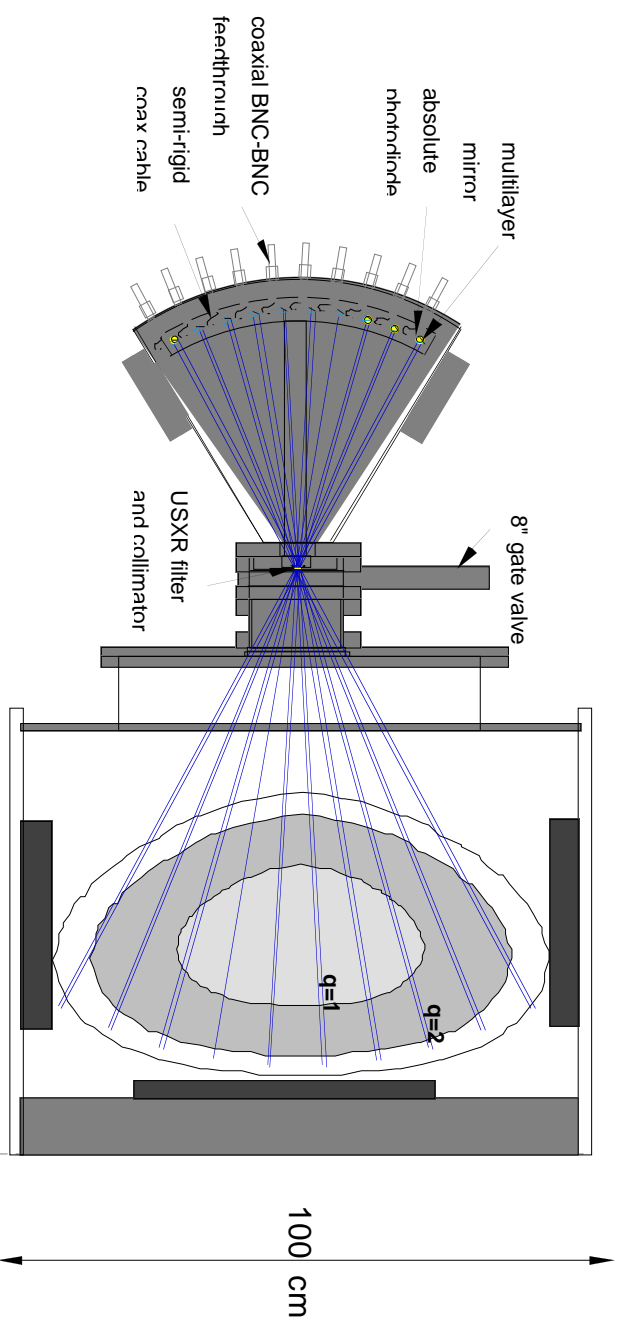
CDX-U typically operates with peak densities in the mid 10^{13} cm^{-3} . Profiles are highly peaked.



Temperature profiles are flat to hollow.
Peak electron temperatures $\sim 100 \text{ eV}$
(ohmic discharge).



Primary diagnostic for lithium concentration in the core plasma will be the JHU multilayer mirror array



Wavelength range	Mirror	Reflectivity	Resolution (%)	Application example (\AA)
12-30 injected Ne IX-X	W/B4C	5-20	0.4-0.6	O VII-VIII,
30-45	Ti/Cr	7-25	0.6-1.5	C V-VI
45-100	Ni/C	20-30	1.5-3	injected B V-VI

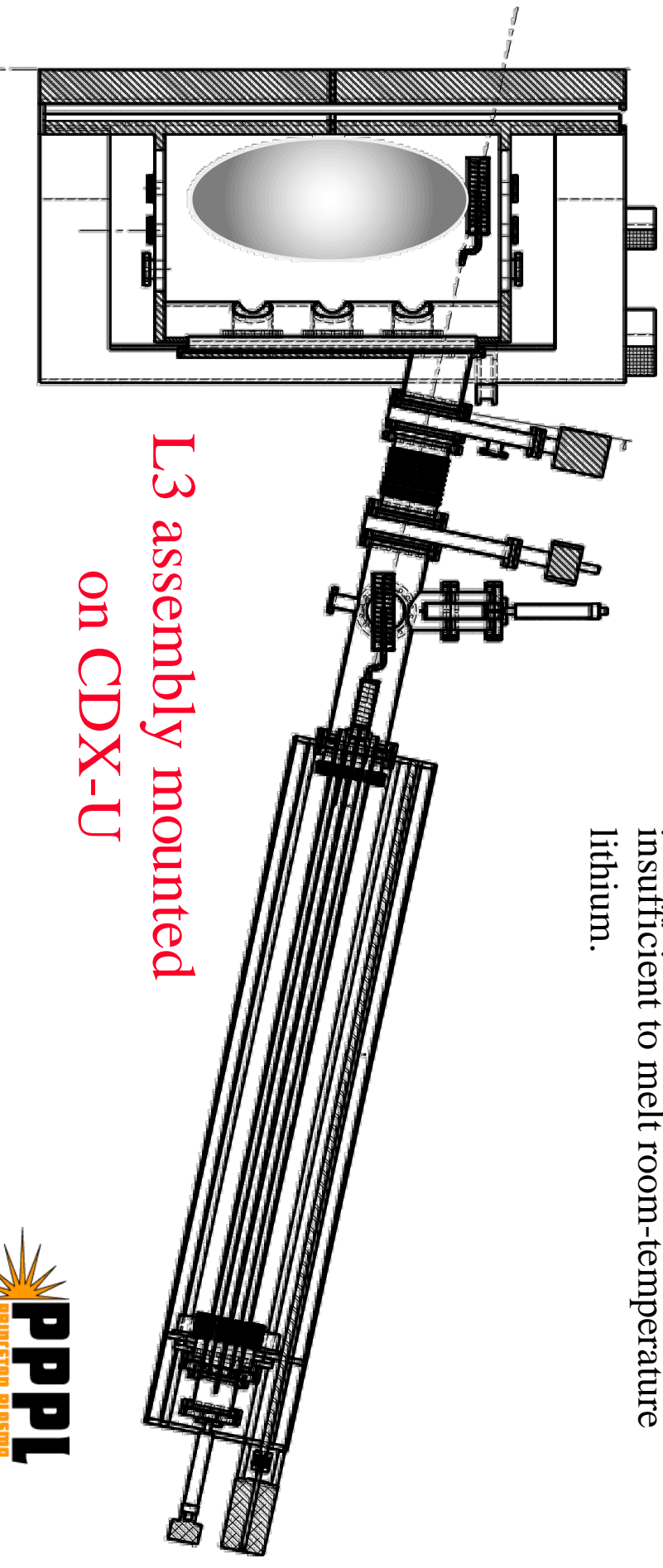
UCSD lithium rail limiter

- ◆ First lithium system scheduled to be tested is now in final design at UCSD.
 - Heated cylindrical rail limiter.
 - Surface will be a stainless steel mesh wet with liquid lithium.
 - » Similar to the T-11M system (Pistunovich et al., J. Nucl. Mater. 1997, vol. 241-243, p. 1190)
 - Lithium will be resupplied from a heated reservoir.
 - Primary limiting surface for the discharge.
- ◆ The porting on one toroidal sector of CDX-U will be reworked to accommodate the liquid lithium limiter (“L3”) and the associated diagnostics.
- ◆ Installation expected in May.

Design of the liquid lithium rail limiter

UCSD/PISCES - R. Doerner, L. Chousal, S. Luckhardt

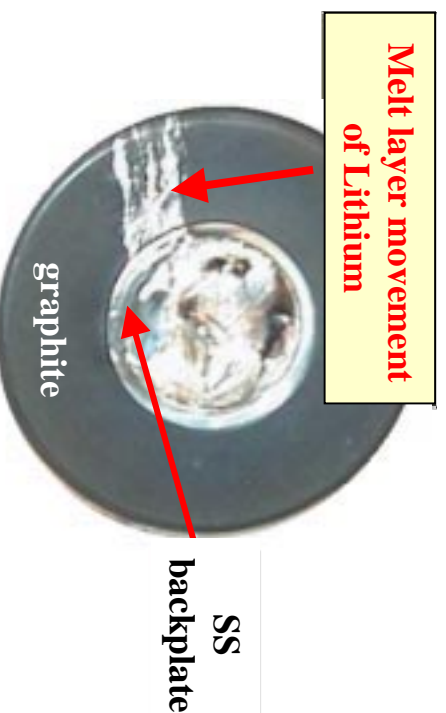
- ◆ Lithium rail “head” can be retracted through an airlock assembly, serviced.
- ◆ Lithium/mesh system independently heated.
 - ΔT from a single CDX shot $\sim 100^\circ\text{C}$; insufficient to melt room-temperature lithium.



L3 assembly mounted
on CDX-U

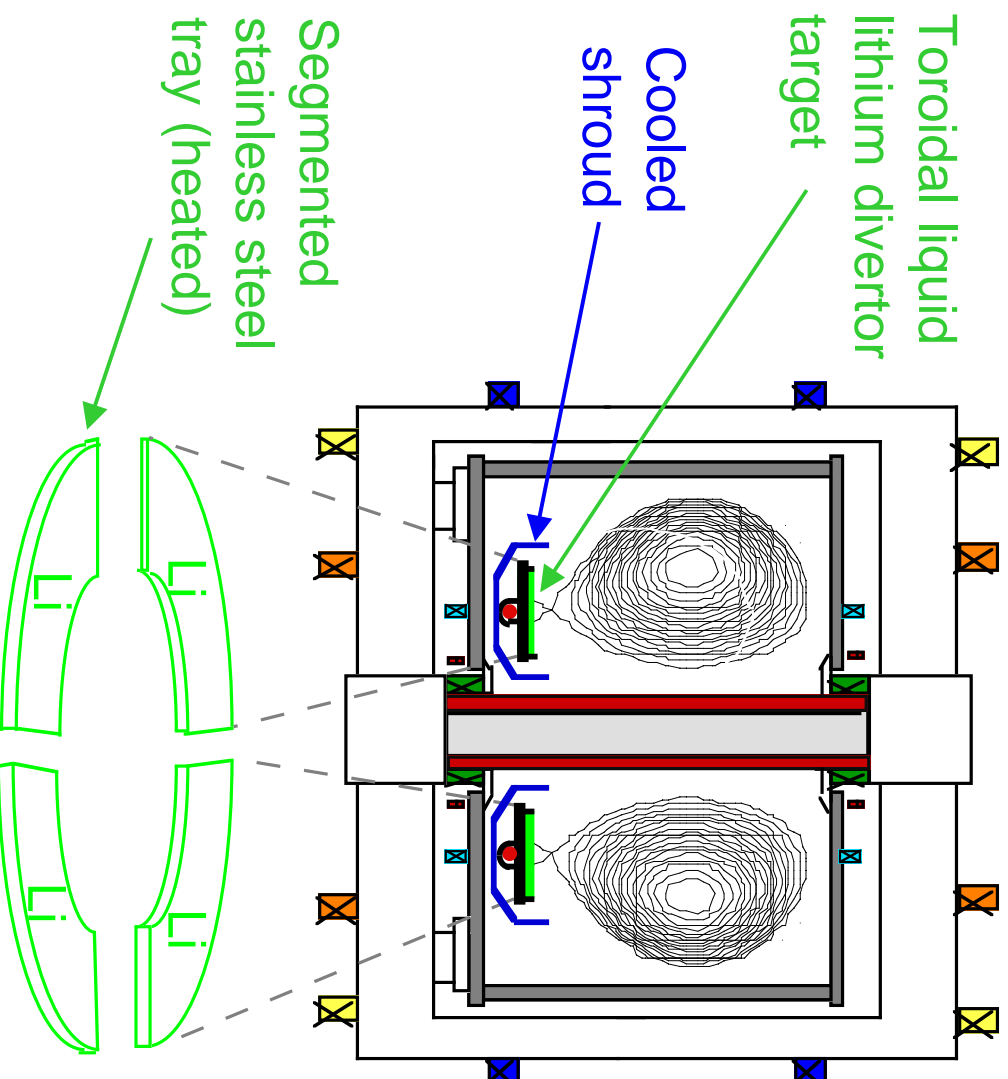
Full toroidal lithium limiter target will be installed following the L3 experiments

- ◆ Preliminary design calls for a 10 cm wide tray.
 - Wet mesh and shallow “pool” designs under study.
 - Silicone cooled shroud will protect the center stack, lower vacuum vessel.
 - Lithium will be loaded into the trough under vacuum and melted.
- ◆ Subsequent installations will utilize larger in-vessel lithium inventories.
 - Fill/drain systems to replace lithium without venting.
 - Electromagnetic restraint to prevent “splashing”.



J x B forces on liquid lithium during X-point strike readily eject lithium from DIII-D DiMES probe (D. Whyte, R. Doerner, S. Seradarian)

Toroidal liquid lithium divertor concept for CDX-U



- ◆ Lithium divertor tray and shroud installed
- ◆ Pumpdown
- ◆ Tray discharge cleaned
- ◆ Load lithium into tray under vacuum
- ◆ Melt lithium ($>300\text{ }^{\circ}\text{C}$)
- ◆ Periodically discharge clean lithium surface

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